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THE CETENE SCALE AND THE INDUCTION PERIOD PRECEDING THE SPONTANEOUS IGNITION OF DIESEL FUELS IN BOMBS*

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During recent years, high-speed diesel engines, requiring special fuels, have come into wider and wider use. Simultaneously the problem of working out a standard method of testing and evaluating fuels has become more urgent.

Boerlage and Broeze (reference 1) suggested comparing the fuel with a mixture of two hydrocarbons - 1-methyl naphthalene and cetene, the former igniting with difficulty, the latter, with ease.

In order to make a comparison it is necessary to select a mixture of these two hydrocarbons so as to give, in a specially constructed diesel engine, a performance equal to that of the fuel under test. The concentration of the cetene in the mixture is then expressed in percentage and is known as the "cetene number" of the fuel.

Standard engines for these tests are sold by the Waukesha company in the United States. However, on account of the expense of these engines and the complexity of the experimentation required with them, an attempt has been made to evaluate diesel fuels by means of a laboratory test. This attempt was directed along two lines:

1) The determination of "diesel indices" or "indices of combustion" from the fundamental physico-chemical constants of the fuel, and

2) The testing of fuels in bombs.

Moore and Kaye (reference 2), Becker and Fischer (reference 3), Butler (reference 4), Heinze and Marder (reference 5), and others followed the first alternative

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and suggested diesel indices calculated from the specific gravity, viscosity, aniline number, boiling point, parachor, refractive index, etc.

Melkumov (reference 6) showed that the qualities of a number of diesel fuels used in the USSR could be correctly estimated by such calculations. However, the method of diesel indices does not give the cetene number with sufficient accuracy and in some cases even gives qualitatively misleading results.

A number of authors, including Hartner-Seberich (reference 7), Bridgeman and Marvin (reference 8), Helmore and Code Holland (reference 9), and Wentzel (reference 10) have conducted work on the standardization of fuels in bombs, but no positive results were obtained, chiefly due to the fact that the tests were made at pressures and temperatures which were too low as compared with those occurring at the top of the compression stroke in a diesel engine. Kaulin, Neumann, and Serbinov (reference 11) have shown that diesel fuels may be gaged by the induction period preceding spontaneous ignition in a heated bomb. In this case the fuels fall into the same order as that found on the cetene scale determined with a Waukesha engine. The authors compared the given diesel fuel with mixtures of cetene and mesitylene and it was found that the resulting cetene number obtained in bombs was in general 5 to 10 units lower than that obtained in tests with the standard engine. For this reason the authors suggested the term "conditional cetene scale" for their scale.

Since the calibrating fuels used in the engine tests are cetene and 1-methyl naphthalene, it was very necessary to carry out tests with these hydrocarbons in a bomb and to establish a new cetene scale on the basis of the results obtained.

These results are reported in the present paper where a comparison is made between the scale obtained with mixtures of cetene and 1-methyl naphthalene in a bomb, and that obtained with the same fuels in a Waukesha engine. The tests were conducted in a metal bomb heated by a Nichrome spiral. The fuel was injected into the bomb from a Bosch jet by means of a specially constructed plunger pump.

The instant of injection and the pressure curve in the bomb were registered by a beam of light which was reflected from a mirror connected to the needle of the jet and to a membrane indicator. The diagram traced by the latter gave the induction period τ which corresponds to the time interval between injection and spontaneous ignition, and which is necessary for the physical (evaporation) and chemical preparation of the fuel.

All the tests were made with constant settings of the jet and pump which gave an injection of approximately 80 mg of fuel each time. This quantity of fuel corresponds to a coefficient of excess air α of about 1.7 at an air pressure of 21 atm., which was sufficient for complete combustion. The induction periods obtained during the combustion of mixtures of cetene and mesitylene, and of cetene and 1-methyl naphthalene are given in tables I and II.

It is clear from these figures that the induction period of mesitylene is much less than that of 1-methyl naphthalene. Since the "conditional cetene scale" was founded on results obtained with cetene and mesitylene, while cetene and 1-methyl naphthalene mixtures were used in obtaining the scale with the engine, the difference between the two scales is understandable.

In constructing both the conditional and the cetene scales we tried as far as possible to keep the pressure and temperature near to those which are known to exist in an engine at the end of the compression stroke. The standard values chosen with this end in view were $p = 21$ atm. and $T = 580°$ C.

The pressures and temperatures at the end of the compression stroke in modern high-speed diesel engines with a compression ratio of 11 to 14 range between 20 and 35 atm. and 450 to 515° C., respectively. Since the temperature of the walls of the bomb was 125° C. higher than the average temperature of enclosed air, the temperatures quoted above correspond to wall temperatures of 575 to 640° C.

It was established in a series of experiments that the effect on the induction period of small pressure and temperature changes, which is so marked below 550° and 20 atm., disappears almost completely at pressures and temperatures above these values. Thus the conditions chosen, namely $p = 21$ atm. and $T = 580°$ C., for the construction of the cetene scale correspond completely to those obtaining in a diesel engine at the end of the compression stroke. A part of the cetene scale is represented in the figure. The circles correspond to the induction periods of the mixtures investigated. It appears from this curve that with low cetene numbers the induction period τ depends very strongly on the cetene number, while when the latter is greater than 50 the changes in τ are insignificant.

In order to determine the cetene numbers of various diesel fuels a number of experiments were made, the results of which are given in table III.

It is clear from this table that at temperatures above 580° Grosnensky gas oil, Surakhansky gas oil and Kara-Chukhursky solyar have the smallest induction periods. Next in order of increasing induction period come export gas oil Binagadinsky solyar, light and heavy Balakhansky solyars. At lower temperatures this order is changed and this explains the lack of success obtained in previous attempts at standardizing diesel fuels in bombs.

The induction periods of these fuels are given on the cetene scale and from this their cetene numbers have been determined. The induction periods and cetene numbers of these fuels determined with a Waukesha engine and in a bomb are compared in table IV. From this table it is clear that the cetene numbers determined according to the method described agree within the limits of experimental error with those measured by means of a Waukesha engine.

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TABLE I

Induction Periods during the Spontaneous Ignition of Mixtures of Cetene and Mesitylene at p = 21 atm.

Temp. °C.	Induction period in milliseconds				
	100 percent cetene	75 percent cetene	50 percent cetene	35 percent cetene	Mesitylene
610	3.1	3.5	4.9	8.6	19.5
600	3.2	3.6	5.0	8.7	20.9
590	3.3	3.65	5.1	8.8	22.0
580	3.5	3.7	5.3	9.0	23.0
570	3.7	4.0	5.4	9.3	24.5
560	3.9	4.2	5.6	9.6	26.0
540	4.3	5.0	7.0	14.9	--
530	4.7	6.1	7.4	18.0	--
520	5.1	8.0	8.8	--	--
510	5.3	9.5	10.6	--	--
500	6.5	12.0	13.0	--	--

TABLE II

Induction Periods during the Spontaneous Ignition of Mixtures of Cetene and 1-Methyl Naphthalene at p = 21 atm.

Temp. °C.	Induction period in milliseconds				
	100 percent cetene	66 percent cetene	50 percent cetene	33 percent cetene	1-methyl naphthalene
600	3.2	3.9	4.5	11.1	38.0
590	3.3	4.0	6.0	11.6	34.3
580	3.5	4.8	6.8	12.0	43.0
570	3.7	4.9	6.9	14.3	58.5
560	3.9	6.15	7.0	15.5	80.8
540	4.3	6.7	8.06	25.0	124.0
530	4.7	7.4	8.3	31.2	--
520	6.1	8.9	13.1	71.6	--
505	–	11.9	16.9	--	--

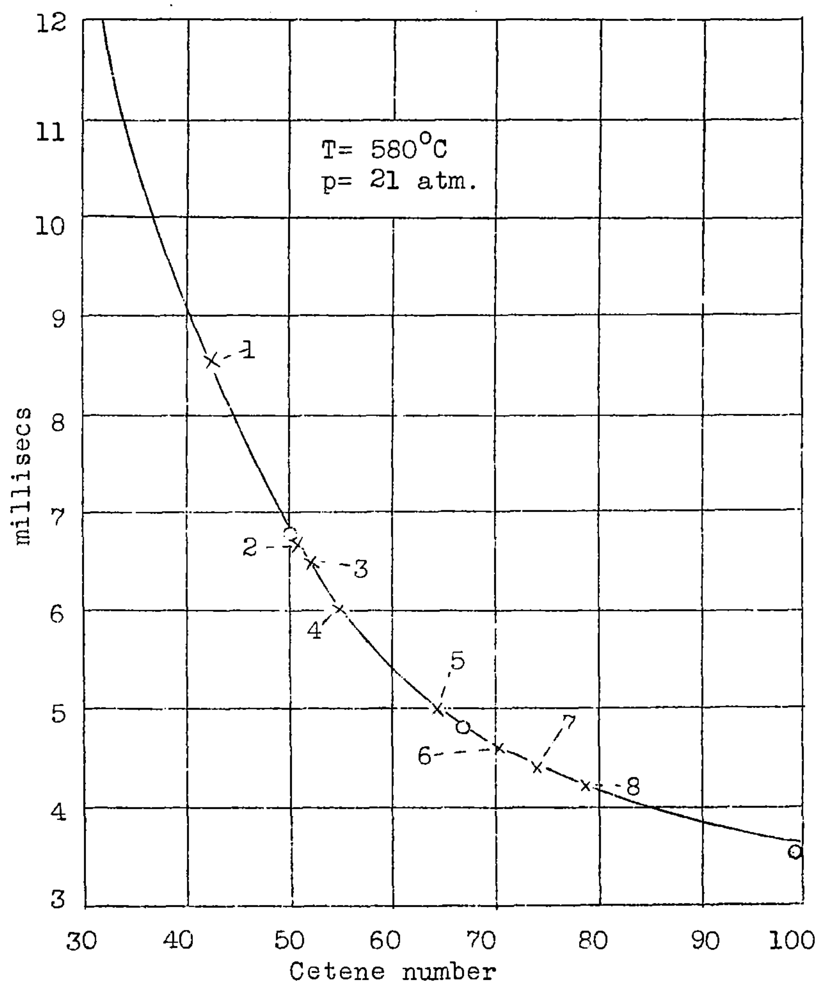
TABLE III

The Influence of Temperature on the Induction Period Preceding the Ignition of Diesel Fuels at p = 21 atm.

T^oC	Induction period in milliseconds							
	Heavy Balakh. solyar	Light Balakh. solyar	Binaga-dinsky solyar	Mixture of solyars	Gas oil for diesel test run	Kara-Chukhur solyar	Surakh. gas oil	Grozn. gas oil
610	7.7	--	6.2	5.4	--	4.5	4.2	--
600	8.0	6.6	6.3	5.6	--	--	4.25	3.9
590	8.3	6.65	6.4	5.8	--	4.55	4.3	4.1
580	8.5	6.7	6.5	6.0	5.0	4.6	4.4	4.2
570	9.2	6.8	7.0	6.3	6.1	--	4.6	5.1
560	9.7	7.0	7.4	6.6	8.2	5.0	4.7	6.1
550	10.2	--	--	7.0	12.9	5.3	4.9	7.5
540	10.8	7.5	8.3	7.7	23.1	5.5	5.2	--
530	11.4	7.8	8.7	8.4	--	5.9	--	--
520	12.1	8.1	9.2	9.5	--	6.5	6.1	--
510	12.9	8.4	--	11.0	--	7.4	--	--
500	13.9	8.7	10.5	13.0	--	9.7	7.4	--

TABLE IV

Fuel	Induction period at p = 21 atm. T = 580°C	Experiments in a bomb		Experiments with a Waukesha engine
		Conditional cetene number	Cetene number	Cetene number
1. Heavy Balakh. solyar	8.5	34	42	40
2. Light Balakh. solyar	6.7	41	50	48.5
3. Binagadin solyar	6.5	42	52	53
4. Mixture of solyars	6.0	44	55	53
5. Gas oil exp.	5.0	52	64	65.5
6. Kara-Chukhur solyar	4.6	57	71	71.5
7. Surakhansky gas oil	4.4	60	74	76
8. Gronznensky gas oil	4.2	64	78	77


T= 580°C
p= 21 atm.
12
11
10
9
8
7
6
5
4
3
millisecs
1
2
3
4
5
6
7
8
30
40
50
60
70
80
90
100
Cetene number